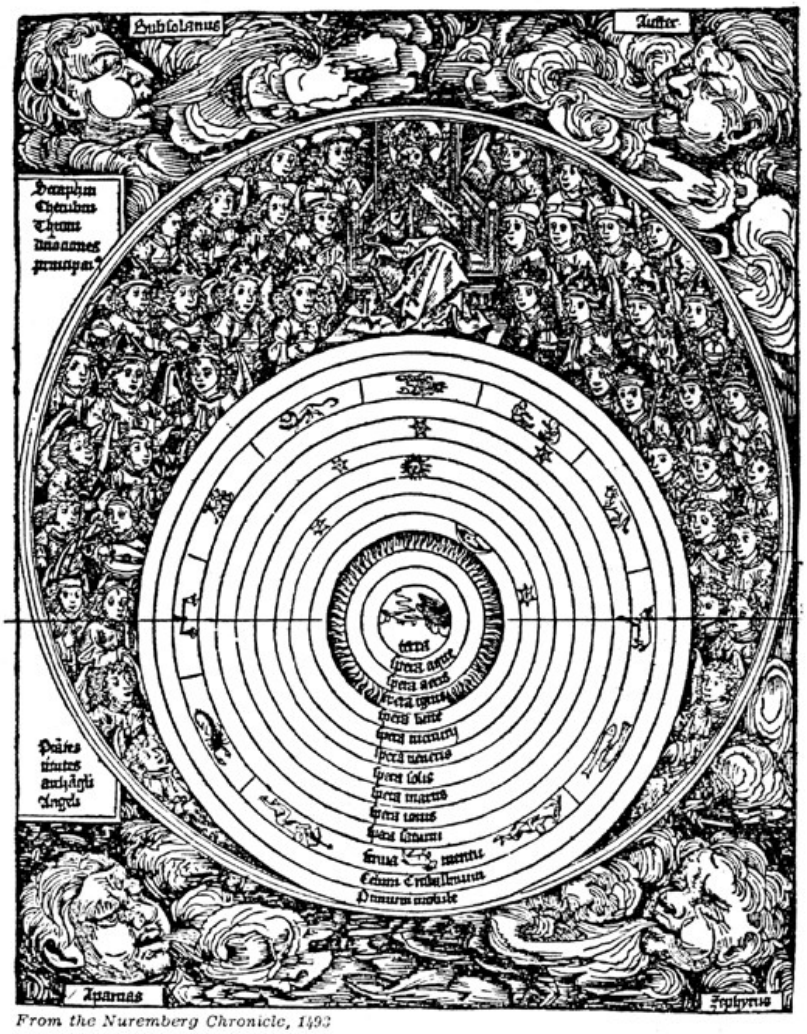
Origins Of Inertia: The Theory Of Impetus



From the Nuremberg Chronicle, 1493

The Universe of Ptolemy

Ptolemy, who lived in the 2d century A.D., placed the earth (*terra*) in the center of the universe. He believed that the earth supported the elements, water, air and fire, and that around the elements revolved a series of epicycles, vast spherical zones or heavens, the smallest enclosing the earth. Each of the heavenly bodies was attached to one of the spheres and caused it to move around the earth at a uniform rate. The moon was attached to the innermost epicycle, and then came Mercury, Venus, the sun, Mars, Jupiter, Saturn and the fixed stars, eight in number. The ninth sphere produced the precession of the equinoxes, and the tenth, the *primum mobile*, supposedly revolved from east to west in 24 hours and carried the hours along with it. Until 1543, when Copernicus published his true system of the universe, people believed in the system of Ptolemy, as pictured here in a woodcut from the *Nuremberg Chronicle*. The artist who designed this old woodcut has added his conception of the heavenly universe: God on His throne surrounded by angels and archangels, seraphim and cherubim, and in the four corners the winds that blow on the earth: *Subsolanus*, the east wind; *Auster*, the south wind; *Aparctias*, the north wind, and *Zephyrus*, the west wind

"As an indication of exactly how good the Ptolemaic model is, modern planetariums are built using gears and motors that essentially reproduce the Ptolemaic model for the appearance of the sky as viewed from a stationary Earth. In the planetarium projector, motors and gears provide uniform motion of the heavenly bodies. One motor moves the planet projector around in a big circle, which in this case is the deferent, and another gear or motor takes the place of the epicycle."

http://www.polaris.iastate.edu/EveningStar/Unit2/unit2_sub1.htm

Nicole Oresme

"In his Livre du ciel et du monde Oresme discussed a range of evidence for and against the daily rotation of the Earth on its axis.[6] From astronomical considerations, he maintained that if the Earth were moving and not the celestial spheres, all the movements that we see in the heavens that are computed by the astronomers would appear exactly the same as if the spheres were rotating around the Earth. He rejected the physical argument that if the Earth were moving the air would be left behind causing a great wind from east to west. In his view the Earth, Water, and Air would all share the same motion.[7]As to the scriptural passage that speaks of the motion of the Sun, he concludes that "this passage conforms to the customary usage of popular speech" and is not to be taken literally.[8] He also noted that it would be more economical for the small Earth to rotate on its axis than the immense sphere of the stars.
[9] **Nonetheless, he concluded that none of these arguments were conclusive and "everyone maintains, and I think myself, that the heavens do move and not the Earth."***"*

https://en.wikipedia.org/wiki/Nicole_Oresme

It's All FIXED!

"The theory of impetus was an auxiliary or secondary theory of Aristotelian dynamics, put forth initially to explain projectile motion against gravity. It was introduced by John Philoponus in the 6th century and elaborated by Nur ad-Din al-Bitruji at the end of the 12th century, but was only established in western scientific thought by Jean Buridan in the 14th century. It is the intellectual precursor to the concepts of inertia, momentum and acceleration in classical mechanics."

https://en.wikipedia.org/wiki/Theory_of_impetus

impetus (n.)

"early 15c., *impetous* "rapid movement, rush;" 1640s, with modern spelling, "force with which a body moves, driving force," from Latin *impetus* "an attack, assault; rapid motion; an impulse; violence, vigor, force;" figuratively "ardor, passion," from *impetere* "to attack," from assimilated form of *in-* "into, in, on, upon" (see in- (2)) + *petere* "aim for, rush at" (see petition (n.))."

A Famed Thought Experiment

"The Buridan impetus theory developed one of the most important thought-experiments in the history of science, namely the so-called 'tunnel-experiment', so important because it brought oscillatory and pendulum motion within the pale of dynamical analysis and understanding in the science of motion for the very first time and thereby also established one of the important principles of classical mechanics. The pendulum was to play a crucially important role in the development of mechanics in the 17th century, and so more generally was the axiomatic principle of Galilean, Huygenian and Leibnizian dynamics to which the tunnel experiment also gave rise, namely that a body rises to the same height from which it has fallen, a principle of gravitational potential energy. As Galileo Galilei expressed this fundamental principle of his dynamics in his 1632 Dialogo:

> *The heavy falling body acquires sufficient impetus [in falling from a given height] to carry it back to an equal height.*

This imaginary experiment predicted that a cannonball dropped down a tunnel going straight through the centre of the Earth and out the other side would go past the centre and rise on the opposite surface to the same height from which it had first fallen on the other side, driven upwards past the centre by the gravitationally created impetus it had continually accumulated in falling downwards to the centre. This impetus would require a violent motion correspondingly rising to the same height past the centre for the now opposing force of gravity to destroy it all in the same distance which it had previously required to create it, and whereupon at this turning point the ball would then descend again and oscillate back and forth between the two opposing surfaces about the centre ad infinitum in principle. Thus the tunnel experiment provided the first dynamical model of oscillatory motion, albeit a purely imaginary one in the first instance, and specifically in terms of A-B impetus dynamics.

However, this thought-experiment was then most cunningly applied to the dynamical explanation of a real world oscillatory motion, namely that of the pendulum, as follows. The oscillating motion of the cannonball was dynamically assimilated to that of a pendulum bob by imagining it to be attached to the end of an immensely cosmologically long cord suspended from **the vault of the fixed stars centred on the Earth***, whereby the relatively short arc of its path through the enormously distant Earth was practically a straight line along the tunnel. Real world pendula were then conceived of as just micro versions of this 'tunnel pendulum', the macro-cosmological paradigmatic dynamical model of the pendulum, but just with far shorter cords and with their bobs oscillating above the Earth's surface* **in arcs corresponding to the tunnel inasmuch as their oscillatory midpoint was dynamically assimilated to the centre of the tunnel as the centre of the Earth.**

Hence by means of such impressive literally 'lateral thinking', rather than the dynamics of pendulum motion being conceived of as the bob inexplicably somehow falling downwards compared to the vertical to a gravitationally lowest point and then inexplicably being pulled back up again on the same upper side of that point, rather it was its lateral horizontal motion that was conceived of as a case of gravitational free-fall followed by violent motion in a recurring cycle, with the bob repeatedly travelling through and beyond the motion's vertically lowest but horizontally middle point that stood proxy for the centre of the Earth in the tunnel pendulum. So on this imaginative lateral gravitational thinking outside the box the lateral motions of the bob first towards and then away from the normal in the downswing and upswing become lateral downward and upward motions in relation to the horizontal rather than to the vertical.

Thus whereas the orthodox Aristotelians could only see pendulum motion as a dynamical anomaly, as inexplicably somehow 'falling to rest with difficulty' as historian and philosopher of science Thomas Kuhn put it in his 1962 The Structure of Scientific Revolutions,[16] on the impetus

theory's novel analysis it was not falling with any dynamical difficulty at all in principle, but was rather falling in repeated and potentially endless cycles of alternating downward gravitationally natural motion and upward gravitationally violent motion. Hence, for example, Galileo was eventually to appeal to pendulum motion to demonstrate that the speed of gravitational free-fall is the same for all unequal weights precisely by virtue of dynamically modelling pendulum motion in this manner as a case of cyclically repeated gravitational free-fall along the horizontal in principle.

In fact the tunnel experiment, and hence pendulum motion, was an imaginary crucial experiment in favour of impetus dynamics against both orthodox Aristotelian dynamics without any auxiliary impetus theory, and also against Aristotelian dynamics with its H-P variant. For according to the latter two theories the bob cannot possibly pass beyond the normal. In orthodox Aristotelian dynamics there is no force to carry the bob upwards beyond the centre in violent motion against its own gravity that carries it to the centre, where it stops. And when conjoined with the Philoponus auxiliary theory, in the case where the cannonball is released from rest, again there is no such force because either all the initial upward force of impetus originally impressed within it to hold it in static dynamical equilibrium has been exhausted, or else if any remained it would be acting in the opposite direction and combine with gravity to prevent motion through and beyond the centre. Nor were the cannonball to be positively hurled downwards, and thus with a downward initial impetus, could it possibly result in an oscillatory motion. For although it could then possibly pass beyond the centre, it could never return to pass through it and rise back up again. For dynamically in this case although it would be logically possible for it to pass beyond the centre if when it reached it some of the constantly decaying downward impetus remained and still sufficiently much to be stronger than gravity to push it beyond the centre and upwards again, nevertheless when it eventually then became weaker than gravity, whereupon the ball would then be pulled back towards the centre by its gravity, it could not then pass beyond the centre to rise up again, because it would have no force directed against gravity to overcome it. For any possibly remaining impetus would be directed 'downwards' towards the centre, that is, in the same direction in which it was originally created.

Thus pendulum motion was dynamically impossible for both orthodox Aristotelian dynamics and also for H-P impetus dynamics on this 'tunnel model' analogical reasoning. But it was predicted by the impetus theory's tunnel prediction precisely because that theory posited that a continually accumulating downwards force of impetus directed towards the centre is acquired in natural motion, sufficient to then carry it upwards beyond the centre against gravity, and rather than only having an initially upwards force of impetus away from the centre as in the theory of natural motion. So the tunnel experiment constituted a crucial experiment between three alternative theories of natural motion.

On this analysis then impetus dynamics was to be preferred if the Aristotelian science of motion was to incorporate a dynamical explanation of pendulum motion. And indeed it was also to be preferred more generally if it was to explain other oscillatory motions, such as the to and fro vibrations around the normal of musical strings in tension, such as those of a zither, lute or guitar. For here the analogy made with the gravitational tunnel experiment was that the tension in the string pulling it towards the normal played the role of gravity, and thus when plucked i.e. pulled away from the normal and then released, this was the equivalent of pulling the cannonball to the Earth's surface and then releasing it. Thus the musical string vibrated in a continual cycle of the alternating creation of impetus towards the normal and its destruction after passing through the normal until this process starts again with the creation of fresh 'downward' impetus once all the 'upward' impetus has been destroyed.

This positing of a dynamical family resemblance of the motions of pendula and vibrating strings with the paradigmatic tunnel-experiment, the original mother of all oscillations in the history of dynamics, was one of the greatest imaginative developments of medieval Aristotelian dynamics in its increasing repertoire of dynamical models of different kinds of motion.

Shortly before Galileo's theory of impetus, Giambattista Benedetti modified the growing theory of impetus to involve linear motion alone:

> *"...[Any] portion of corporeal matter which moves by itself when an impetus has been impressed on it by any external motive force has a natural tendency to move on a rectilinear, not a curved, path."[18]*

Benedetti cites the motion of a rock in a sling as an example of the inherent linear motion of objects, forced into circular motion."

Let's Swing Baby!

"One of the earliest known uses of a pendulum was a 1st-century seismometer device of Han Dynasty Chinese scientist Zhang Heng.[18] Its function was to sway and activate one of a series of levers after being disturbed by the tremor of an earthquake far away.[19] Released by a lever, a small ball would fall out of the urn-shaped device into one of eight metal toad's mouths below, at the eight points of the compass, signifying the direction the earthquake was located.[19]

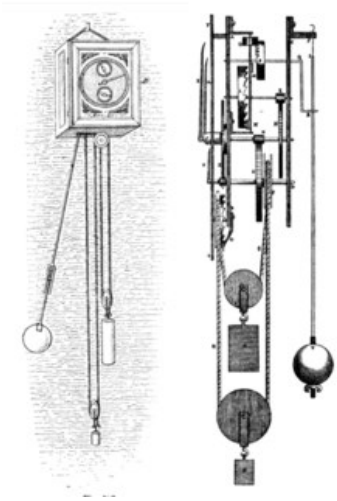
Many sources[20][21][22][23] claim that the 10th-century Egyptian astronomer Ibn Yunus used a pendulum for time measurement, but this was an error that originated in 1684 with the British historian Edward Bernard.[24][25][26]

During the Renaissance, large pendulums were used as sources of power for manual reciprocating machines such as saws, bellows, and pumps.[27]Leonardo da Vinci made many drawings of the motion of pendulums, though without realizing its value for timekeeping.

1602: Galileo's research

Italian scientist Galileo Galilei was the first to study the properties of pendulums, beginning around 1602.[28] The earliest extant report of his research is contained in a letter to Guido Ubaldo dal Monte, from Padua, dated November 29, 1602.[29] His biographer and student, Vincenzo Viviani, claimed his interest had been sparked around 1582 by the swinging motion of a chandelier in the Pisa cathedral.[30][31] Galileo discovered the crucial property that makes pendulums useful as timekeepers, called isochronism; the period of the pendulum is approximately independent of the amplitude or width of the swing.[32] He also found that the period is independent of the mass of the bob, and proportional to the square root of the length of the pendulum. He first employed freeswinging pendulums in simple timing applications. His physician friend, Santorio Santorii, invented a device which measured a patient's pulse by the length of a pendulum; the pulsilogium.[28] In 1641 Galileo

conceived and dictated to his son Vincenzo a design for a pendulum clock;[32] Vincenzo began construction, but had not completed it when he died in 1649.[33] The pendulum was the first harmonic oscillator used by man."



Arguing with Buckets

"Isaac Newton's rotating bucket argument (also known as "Newton's bucket") was designed to demonstrate that true rotational motion cannot be defined as the relative rotation of the body with respect to the immediately surrounding bodies. It is one of five argumentsfrom the "properties, causes, and effects" of true motion and rest that support his contention that, in general, true motion and rest cannot be defined as special instances of motion or rest relative to other bodies, but instead can be defined only by reference to absolute space. Alternatively, these experiments provide an operational definition of what is meant by "absolute rotation", and do not pretend to address the question of "rotation relative to what?"."

Newton Was Prejudiced Against An Immobile Earth & For A Heliocentric Model of the Cosmos

"Despite their embrace of the principle of rectilinear inertia and the recognition of the kinematical relativity of apparent motion (which underlies whether the Ptolemaic or the Copernican system is correct), natural philosophers of the seventeenth century continued to consider true motion and rest as physically separate descriptors of an individual body. The dominant view Newton opposed was devised by René Descartes, and was supported (in part) by Gottfried Leibniz. It held that empty space is a metaphysical impossibility because space is nothing other than the extension of matter, or, in other words, that **when one speaks of the space between things one is actually making reference to the relationship that exists between those things and not to some entity that stands between them**. *Concordant with the above understanding, any assertion about the motion of a body boils down to a description over time in which the body under consideration is at t1 found in the vicinity of one group of "landmark" bodies and at some t2 is found in the vicinity of some other "landmark" body or bodies"*

https://en.wikipedia.org/wiki/Bucket_argument

NEWTON'S BUCKET Explained

The "Fixed Stars" Are resorted to as explanation for the famed bucket experiment, yet this is not the only possible explanation. Relative motion is another option as is **the Earth itself,** which the 'fixed stars' seem to be fixed about.

The Quadrivium: The Subject Astronomy Used to Be Called Cosmology

"The quadrivium (plural: quadrivia[1]) are the four subjects, or arts, taught after teaching the trivium. The word is Latin, meaning "the four ways" (or a "place where four roads meet"),[2] and its use for the four subjects has been attributed to Boethius or Cassiodorus in the 6th century.[3][4] Together, the trivium and the quadrivium comprised the seven liberal arts (based on thinking skills),[5] as opposed to the practical arts (such as medicine and architecture).

The quadrivium consisted of arithmetic, geometry, music, and astronomy. These followed the preparatory work of the trivium made up of grammar, logic, and rhetoric. In turn, the quadrivium was considered preparatory work for the serious study of philosophy (sometimes called the "liberal art par excellence") and theology."

"At many medieval universities, this would have been the course leading to the degree of Master of Arts (after the BA). After the MA, the student could enter for bachelor's degrees of the higher faculties (Theology, Medicine or Law). To this day, some of the postgraduate degree courses lead to the degree of Bachelor (the B.Phil and B.Litt. degrees are examples in the field of philosophy).

The study was eclectic, approaching the philosophical objectives sought by considering it from each aspect of the quadrivium within the general structure demonstrated by Proclus (412–485 AD), **namely arithmetic and music on the one hand, and geometry and cosmology on the other**.

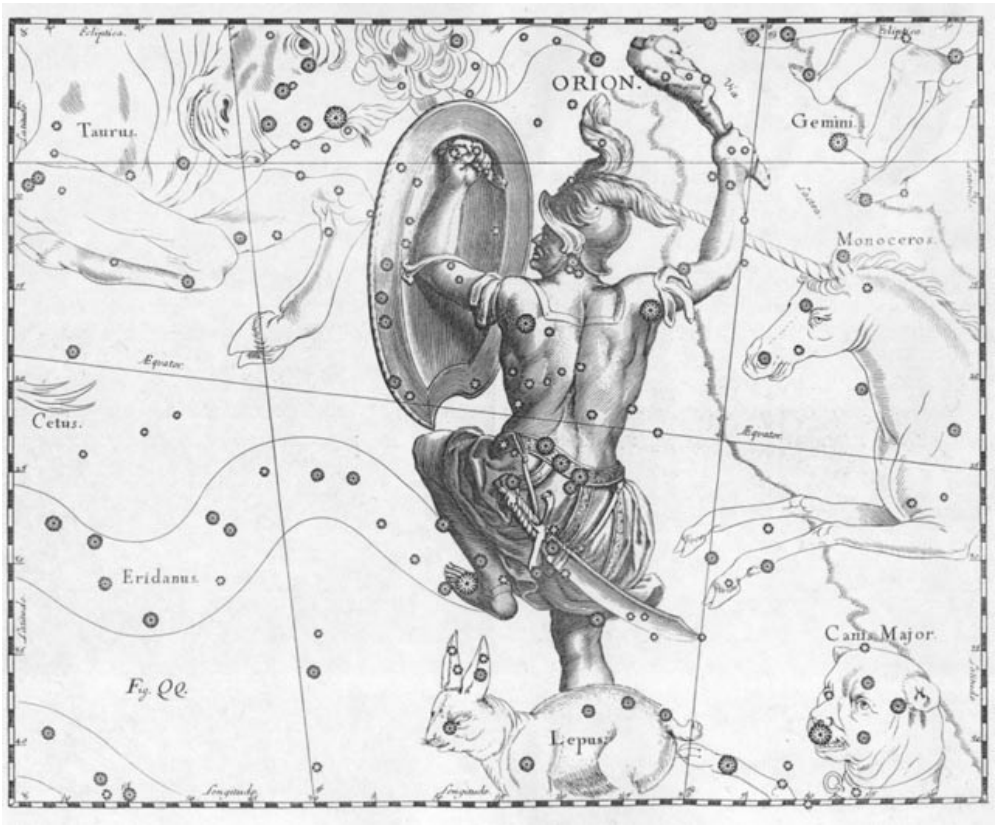
The subject of music within the quadrivium was originally the classical subject of harmonics, in particular the study of the proportions between the music intervals created by the division of a monochord. A relationship to music as actually practised was not part of this study, but the framework of classical harmonics would substantially influence the content and structure of music theory as practised both in European and Islamic cultures."

https://en.wikipedia.org/wiki/Quadrivium

Despite Claims of Slight Parallax, The Zodiac Remains The Same

"The current list of 88 constellations recognized by the International Astronomical Union since 1922 is based on the 48 listed by Ptolemy in his Almagest in the 2nd century, with early modern modifications and additions (most importantly introducing constellations covering the parts of the southern sky unknown to Ptolemy) by Petrus Plancius (1592, 1597/98 and 1613), Johannes Hevelius (1690) and Nicolas Louis de Lacaille (1763)." https://en.wikipedia.org/wiki/Constellation#Early_Modern_era

The constellations retain their shapes and relative distances despite the supposed motions of the Earth during its imagined journey through the cosmos. This would seem to be a problem for Heliocentric-based models of the Universe.



https://en.wikipedia.org/wiki/Constellation

Fixed or Not so FIxed?

"Fixed stars do have parallax, which is a change in apparent position caused by the orbital motion of the Earth. This effect was small enough not to have been noticed until the 19th century. It can be used to find the distance to nearby stars. This motion is only apparent; it is the Earth that moves.

The fixed stars exhibit real motion as well, however. This motion may be viewed as having components that consist in part of motion of the galaxy to which the star belongs, in part of rotation of that galaxy, and in part of motion peculiar to the star itself within its galaxy.

This real motion of a star is divided into radial motion and proper motion, with "proper motion" being the component across the line of sight. In 1718 Edmund Halley announced his discovery that the fixed stars actually have proper motion. Proper motion was not noticed by ancient cultures because it requires precise measurements over long periods of time to notice. In fact, the night sky today looks very much as it did thousands of years ago, so much so that some modern constellations were first named by the Babylonians.

A typical method to determine proper motion is to measure the position of a star relative to a limited, selected set of very distant objects that exhibit no mutual movement, and that, because of their distance, are* ASSUMED *to have very small proper motion. *Another approach is to compare photographs of a star at different times against a large background of more distant objects. The star with the largest known proper motion is Barnard's Star."* https://en.wikipedia.org/wiki/Fixed_stars

cosmos (n.)

c. 1200 (but not popular until 1848, as a translation of Humboldt's Kosmos), from Latinized form of Greek kosmos "order, good order, orderly arrangement," a word with several main senses rooted in those notions: The verb kosmein meant generally "to dispose, prepare," but especially "to order and arrange (troops for battle), to set (an army) in array;" also "to establish (a government or regime);" "to deck, adorn, equip, dress" (especially of women). Thus kosmos had an important secondary sense of "ornaments of a woman's dress, decoration" (compare kosmokomes "dressing the hair") as well as "the universe, the world."

Pythagoras is said to have been the first to apply this word to "the universe," perhaps originally meaning "the starry firmament," but later it was extended to the whole physical world, including the earth. For specific reference to "the world of people," the classical phrase was he oikoumene (ge) "the inhabited (earth)." Septuagint uses both kosmos and oikoumene. Kosmos also was used in Christian religious writing with a sense of "worldly life, this world (as opposed to the afterlife)," but the more frequent word for this was aion, literally "lifetime, age."

https://en.wikipedia.org/wiki/Cosmology

"Cosmology (from the Greek κόσμος, kosmos "world" and -λογία, -logia "study of"), is the study of the origin, evolution, and eventual fate of the universe. Physical cosmology is the scholarly and scientific study of the origin, evolution, large-scale structures and dynamics, and ultimate fate of the universe, as well as the scientific laws that govern these realities.[1] Religious or mythological cosmology is a body of beliefs based on mythological, religious, and esoteric literature and traditions of creation and eschatology.

Physical cosmology is studied by scientists, such as astronomers and physicists, as well as philosophers, such as metaphysicians, philosophers of physics, and philosophers of space and time. Because of this shared scope with philosophy, theories in physical cosmology may include both scientific and non-scientific propositions, and may depend upon assumptions that can not be tested. Cosmology differs from astronomy in that the former is concerned with the Universe as a whole while the latter deals with individual celestial objects. Modern physical cosmology is dominated by the Big Bang theory, which attempts to bring together observational astronomy and particle physics;[2]more specifically, a

standard parametrisation of the Big Bang with dark matter and dark energy, known as the Lambda-CDM model.

The term cosmology was first used in 1730 by German philosopher Christian Wolff in Cosmologia Generalis.[citation needed] Theoretical astrophysicist David N. Spergel has described cosmology as a "historical science" because "when we look out in space, we look back in time" due to the finite nature of the speed of light."

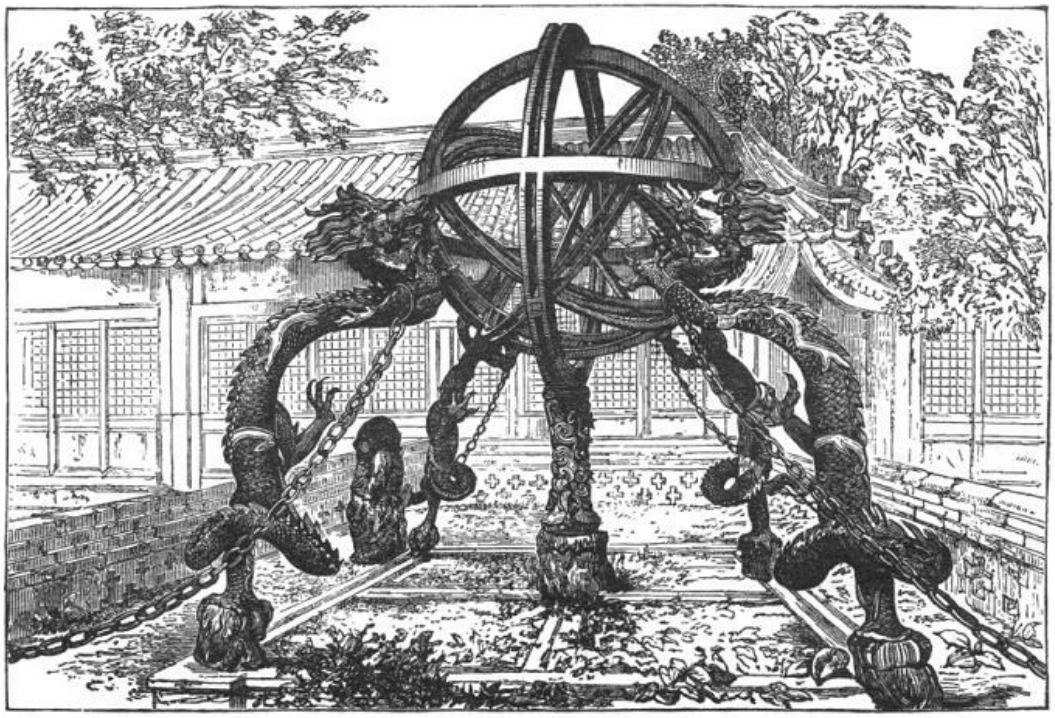


FIG. 34.—BRONZE DRAGONS SUPPORTING THE ARMILLARY SPHERE, OBSERVATORY, PEKIN.

"This theory of heavenly motion is a radical break with the traditional view"

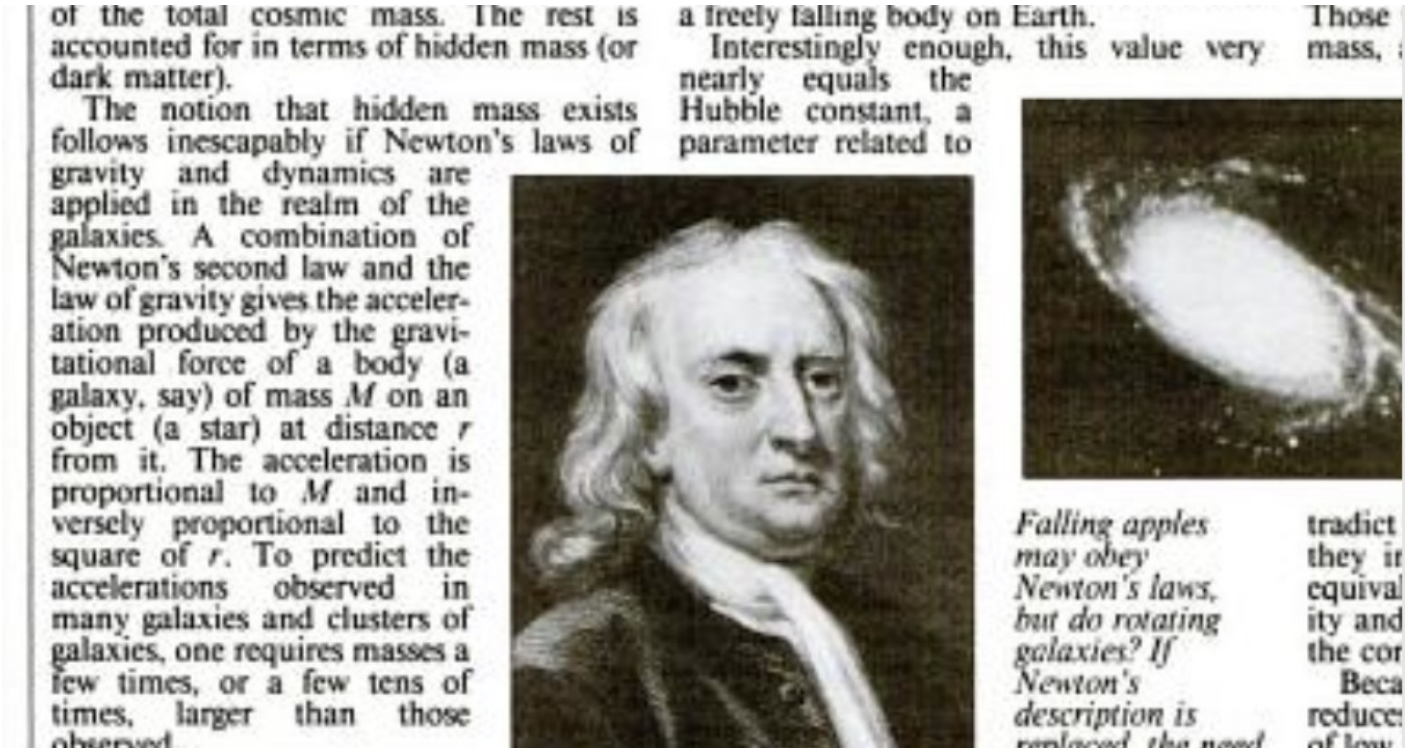
"This theory of heavenly motion is a radical break with the traditional view. **Traditionally, back to Aristotle, celestial and terrestrial phenomena were made of different stuff and so obeyed related but separate laws of physics; the impetus theory enabled philosophers to include celestial motion into the same theory used to describe terrestrial motion.**

Yet, though impetus theory appears sensible in many ways, it is in contradiction so many things that are observed. Common sense says Aristotle might still be right.

So, even Buridan retains the traditional view of solid celestial spheres (not planets) being the objects in motion.

And Oresme ultimately believed that angles moved the celestial spheres. "

http://www.vanderbilt.edu/AnS/physics/astrocourses/ast203/impetus_theory.html



of the total cosmic mass. The rest is accounted for in terms of hidden mass (or dark matter).

The notion that hidden mass exists follows inescapably if Newton's laws of gravity and dynamics are applied in the realm of the galaxies. A combination of Newton's second law and the law of gravity gives the acceleration produced by the gravitational force of a body (a galaxy, say) of mass M on an object (a star) at distance r from it. The acceleration is proportional to M and inversely proportional to the square of r. To predict the accelerations observed in many galaxies and clusters of galaxies, one requires masses a few times, or a few tens of times, larger than those observed

a freely falling body on Earth.

Interestingly enough, this value very nearly equals the Hubble constant, a parameter related to

Those mass,

Falling apples may obey Newton's laws, but do rotating galaxies? If Newton's description is

tradict they ir equival ity and the cor

Beca reduce

We have no *a priori* reason to doubt the adequacy of the physical laws leading to the hidden mass hypothesis. Nevertheless, I have suggested (in a series of papers published in *The Astrophysical Journal* in 1983) that the large mass discrepancies

for hidden mass disappears

the expansion of the Universe, times the speed of light. (Thus, a particle starting from rest and having this acceleration approaches the speed of light in the lifetime

Gravity Falls

Newtonian gravity falls down

Moto Milgrom argues that hidden physics, not hidden mass, is needed to explain how galaxies move

COMMON belief has it that visible matter in the universe (stars, interstellar gas, and so on) constitutes only a small fraction (less than 10 per cent) of the total cosmic mass. The rest is accounted for in terms of hidden mass (or dark matter).

The notion that hidden mass exists follows inescapably if Newton's laws of gravity and dynamics are applied in the realm of the galaxies. A combination of Newton's second law and the law of gravity gives the acceleration produced by the gravitational force of a body (a galaxy, say) of mass M on an object (a star) at distance r from it. The acceleration is proportional to M and inversely proportional to the square of r. To predict the accelerations observed in many galaxies and clusters of galaxies, one requires masses a few times, or a few tens of times, larger than those observed.

Hale Observatories

Falling apples may obey Newton's laws, but do rotating galaxies? If Newton's description is replaced, the need for hidden mass disappears

We have no *a priori* reason to doubt the adequacy of the physical laws leading to the hidden mass hypothesis. Nevertheless, I have suggested (in a series of papers published in *The Astrophysical Journal* in 1983) that the large mass discrepancies observed in astronomical systems are not due to dark matter but to a breakdown of the Newtonian laws of dynamics. I doubt very much whether Newton himself would have put forth his laws in the form that is now known—and feign the hypothesis of hidden mass—if he had all the data we now have. His law was derived from data for the Solar System alone, and Newtonian dynamics have not been tested in any circumstances similar to those in galaxies.

What alternative description could replace Newtonian dynamics to explain the motion of both the Solar System and the galaxies? The alternative I have proposed, called MOND (for Modified Non-relativistic Dynamics), assumes that the Newtonian laws are a good approximation only for accelerations a, which are much greater than some critical acceleration constant a^*. At accelerations smaller than a^* it is the square of the accleration (instead of the acceleration itself) which is proportional to the mass of the pulling body and inversely proportional to the distance squared.

MOND leads to two critically important conclusions. First, the need to assume that hidden mass exists in galaxies disappears.

Secondly, although many systems of very different types were involved in the analysis, they could be explained with the one expression given above and only one, *a priori* unknown, constant a^*. This constant a^* was determined from the data in a few independent ways, all of which led to a value of the critical acceleration some 10^{11} times smaller than the acceleration of a freely falling body on Earth.

Interestingly enough, this value very nearly equals the Hubble constant, a parameter related to the expansion of the Universe, times the speed of light. (Thus, a particle starting from rest and having this acceleration approaches the speed of light in the lifetime of the Universe). If this near equality is not just a chance coincidence, it probably points to a deep connection between local dynamics and global properties of the Universe. This has been the basis of Mach's principle, for example (*New Scientist*, 20/27 December 1984, p 12).

In addition, several other properties of galaxies follow as unavoidable consequences from MOND. The hidden mass hypothesis has so far had nothing to offer in the way of an explanation for any of these phenomena, but no known experimental result has so far been found to conflict with MOND.

MOND makes two types of predictions. Those which can be mimicked by hidden mass, and those which are incompatible with the hypothesis of hidden mass. The latter type, if verified (none has been tested yet), will rule out dark matter as an explanation of the mass discrepancy.

The predictions which have been considered so far fall into three categories. Some amount to saying that following Newtonian laws blindly will lead to the unacceptable result of negative hidden masses in some systems. Others contradict the hidden mass hypothesis, because they involve a breakdown of the strong equivalence principle. This says that gravity and acceleration are equivalent, and is the cornerstone of general relativity.

Because the theory of general relativity reduces to Newton's dynamics in the limit of low velocities (for all accelerations), it is inconsistent with MOND and will have to be amended if MOND turns out to be correct. We do not yet have a satisfactory relativistic theory incorporating MOND. The need for such a theory is particularly pressing, because without it we lack the tool to describe the Universe as a whole.

Whatever the outcome of this line of research, it is salutary to be reminded that alternatives to Newton's laws may be needed to explain the dynamics of large aggregates of matter. □

Moto Milgrom is a professor of astrophysics at the physics department of the Weizmann Institute, Rehovot, Israel.

Science and the common man

Scientists are failing to get the message across, says Ted Nield

POPULAR debates touching upon science and morality often reveal far more about the public view of science than the matter in question. In recent weeks, the dilemma over *in vitro* fertilisation and embryological research has provided a perfect example. The media have fastened upon its potential for generating misplaced sympathy, and Enoch Powell has won the second reading of his Unborn Children (Protection) Bill—his bill of cellular rights.

A leading embryologist was being interviewed on the BBC's lunchtime news the day before the vote that gave Powell's bill its second reading. The need for research into the development of very early embryos was essential, he said. "But surely," the interviewer asked, "you must have done some research to get this far?" The professor nodded. "Well then," the interviewer said, "don't you know enough?"

Such a question would never occur to a scientist. And because scientists tend to mingle with other scientists, suddenly being asked it in a television studio is liable to leave them gobsmacked. It is a question which, if asked by a student, would cause that sense of thoracic implosion which is brought on by the realisation that *nothing has sunk in*. But what are the mistaken assumptions about science that lie behind such a question?

First, there is the common idea that science exists solely for the amassing of facts. People who secretly think this tend to use the expression "the sum total of human knowledge". Powell himself has used it in the House. Secondly, we find the belief that the number of such facts is finite, and that it is possible when you know, say, 80 per cent of them, to call a halt. And thirdly, one senses the feeling that theoretical embryology exists (or should exist) exclusively to allow doctors to perform *in vitro* fertilisation and use it to cure certain forms of infertility. Now that we can do it, the subject is closed. Science as means.

How sad all this is. How many scientists would there be, I wonder, if filling up the tank of facts were all there was to do? ▸

Dr Ted Nield observes and writes about science from a safe distance.

A Model that is Neither Elegant Nor Simple

The Earth's axial tilt and it's fixation with the Fixed Stars shows one of the problems with Heliocentric based theories.

Build a Model Earth, Moon and Sun Orbiter

Tags: NASA, Newton, inertia, impetus, Galileo, Kepler, Cosmos, science, Flat Earth, Geocentric, Helicentrism, Heliocentric, model, Models of Earth, Geocentrism, Heliocentrism
March 3, 2016